INLAND FLOODING *in* ATLANTIC CANADA

NOVA SCOTIA

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Canada

INLAND FLOODING *in* ATLANTIC CANADA

Report Prepared by: Brian Burrell and commissioned by the Atlantic Climate Solutions Association (ACASA), a non-profit organization formed to coordinate project management and planning for climate change adaptation initiatives in Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland and Labrador, and supported through the Regional Adaptation Collaborative, a joint undertaking between the Atlantic provinces, Natural Resources Canada, and regional municipalities and other partners.

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SACCA est un organisme à but non lucratif formé pour coordonner la gestion de projet et la planification des initiatives d'adaptation au changement climatique en Nouvelle-Écosse, du Nouveau-Brunswick, Île du Prince Édouard et Terre-Neuve et soutenu par la collaboration pour l'adaptation régionale, une entreprise commune entre les provinces de l'Atlantique, Ressources naturelles Canada et municipalités régionales et d'autres partenaires.

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Flooding along Saint John River, Jemseg, 2008 (Paul Jordan)

Introduction

Evidence exists that human activities have altered the global climate and will continue to do so throughout the 21st century, significantly affecting components of the hydrologic cycle (IPCC 2001a). Changes in the seasonality, intensity, magnitudes, and types of precipitation events, storm patterns, river ice processes, and sea level are expected to aggravate flooding in many parts of the world. Climate change is expected to increase flood hazards in Atlantic Canada. Precautionary measures are needed today to lessen the potential for extensive flooding in the future, with consequent rapidly rising costs.

Adaptation is defined as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC 2007).

With respect to inland floods, adaptation refers to those practical steps to protect communities from the detrimental impacts of climate change on flood characteristics—such as flood magnitude, frequency, extent, and severity—that result in increased direct, indirect, and intangible flood damages. Auld et al. (2006) stated that reducing societal vulnerability to weather-related disasters under current and changing climate conditions will require a diverse and interconnected range of adaptive actions. Some adaptive actions they identified are hazard identification and risk assessment, comprehensive emergency and disaster management, improved predictions of high-impact weather, better land use planning, strategic environmental and ecosystem protection, continuously updated and improved climatic design values, and changes to infrastructure codes and standards to support disaster-resistant infrastructure.

This paper contains a description of the inland flooding issue and presents its relevance and strategic importance with respect to climate change adaptation. The next section is a discussion of the challenges, barriers, gaps, and needs to lessen potential damages associated with future inland flooding. This is followed by a brief overview of some current projects and activities, and finally some concluding remarks and recommendations.

BACKGROUND

Floods in Atlantic Canada

The occurrence of floods is influenced by natural factors (weather, terrain, vegetation, soils) and some human activities. Inland flooding includes open-water floods from regional moderate-intensity rainfall and snowmelt, local floods from inadequate storm-water drainage or high water tables, flash floods from rapid watershed response to high-intensity precipitation events, flooding because of full or partial flow obstruction (e.g., ice jams), and surges owing to failure of upstream flow obstructions. Floods can result in physical devastation, perils to human safety, threats to human health from contamination of water and the spread of water-borne diseases, detrimental effects on ecosystems, and severe economic losses to individuals and society. Smaller (non-catastrophic floods) often supply benefits, as they transport nutrients, help maintain ecosystems and flood-plain biodiversity, and contribute to groundwater recharge.

Flooding: Canada Water Book (Andrews 1993) provides an overview of flooding in Canada and an introduction to flood damage reduction and assistance programs. Flooding in Canada has resulted directly and indirectly in the deaths of at least 198 people and several billion dollars of damage during the 20th century (Natural Resources Canada 2006). Nationally, over 65 per cent of flood disasters are the result of snowmelt runoff, storm rainfall, or rain-on-snow; other causes of flooding including hurricanes, ice jams, and combinations of factors. Combinations of snowmelt runoff and storm rainfall are considered to be rain-on-snow.

Inland flooding is a common occurrence in Atlantic Canada. In Newfoundland and Labrador, inland floods are caused by rain combined with snowmelt and ice jamming. More than 57 communities have been affected by flooding that resulted in over $40 million in damage over 15 years. Increasing population density around water bodies and the higher values of waterfront property have aggravated the flooding problem. In September 2010, Hurricane Igor struck eastern Newfoundland, producing torrential rainfall that resulted in widespread and severe flooding and temporarily isolating over 150 communities. Igor, with more than $65 million in insurance claims (CBC 2010), was the costliest hurricane in Newfoundland history, with much of the damage being flood related.

In Nova Scotia, inland flooding can be caused by torrential rainfalls, sudden thaws, and failure of infrastructure. Flood-plain areas include those along the Musquodoboit River, the Sackville and Little Sackville Rivers, East River (Pictou), Antigonish-area rivers, and Truro-area rivers.

In Prince Edward Island, inland flooding is primarily the result of heavy precipitation, often as a result of extra-tropical storms (remnants of hurricanes).

In New Brunswick, inland flooding is primary the result of rain or rain-on-snow events, ice jamming, or a combination of these factors. The areas most prone to inland flooding (in terms of flood area and potential flood severity) are along the Saint John River from Fredericton to Lower Jemseg, the Kennebecasis River (and tributaries) from the Sussex area to Hampton, and Marsh Creek in the City of Saint John; past flooding events have occurred along many rivers and streams throughout the province.

Future flood damages will depend on present-day land use and infrastructure decisions as well as future climatic conditions. Flood damages are predicted to increase unless current flood-management policies and infrastructure are changed (see IPCC 2007).

Flood Management

Any human activity to prevent loss of life, property, and economic productivity from floods is defined as flood management. Flood management is often more about managing human activities in areas of known or expected flood hazard than the management of floodwater. In this paper, the terms flood management and flood damage reduction are used interchangeably, although in some technical and planning literature, subtle differences may be assigned to these terms. Inherent in flood management is hazard identification and risk assessment. A hazard exists when a particular situation or event has the potential to cause harmful effects. Risk is a combination of two factors: the probability that an adverse event will occur and its consequences on human and natural systems. Climate-related risk results from the interaction of climatic hazards with the exposed systems. Risk may also be quantified as the probability of climate hazard multiplied by a given system's vulnerability (see also Levina and Tirpak 2006; Engineers Canada 2007).

Flood avoidance often is the preferred means of reducing the risk of potential future flood damage. This means that development generally should not be undertaken in identified flood risk areas. If development does take place in such areas, flood-proofing measures should be incorporated in the planning, design, and construction of the development.

Flood damage reduction includes measures that prevent floods, reduce the probability of a flood, or lessen the damaging effects of unavoidable floods (Burrell et al. 2007). Until the middle of the 20th century, the predominant approach was to construct structural (flood control) measures, such as dams and levees, to manage the flow of water and to keep land from being inundated. In the latter half of the century, the emphasis shifted to human adjustment to floods; this involved the identification of flood hazard and the introduction of planning controls, public education, and financial incentives/disincentives to modify human activities in flood-prone areas.

The contemporary approach is to consider all feasible structural and non-structural measures to yield a cost-effective strategy for a specific flood situation, compatible with current government policies, priorities, and funds (Burrell et al. 2007). Lists of structural and non-structural flood management measures are contained in several papers and reports dealing with flood damage reduction (including Davar et al. 2001; Kundzewicz 2002; Thampapillai and Musgrave 1985; UNISDR 2002).

Davar et al. (2001) present some basic principles with respect to flood damage reduction. One is that the extent of an action should relate to the severity of the problem and the capability to lessen the problem. The authors also state that flood damage reduction should be based on potential risks and associated net costs, should be for the public good, and should be equitable.

Flood Magnitude and Sustainable infrastructure Design

The potential magnitude of an inland flood is a factor considered in the design of infrastructure along or near rivers, whether for flood control, water supply, transportation, or other purposes. The *design flood* is defined as the flood magnitude that can be passed safely without damage, destruction, or operational failure of water-related infrastructure, such as a culvert or levee. A larger design flood affords a greater degree of safety. Cost, however, is always a consideration in the development of infrastructure; the aim is usually to optimize economic efficiency by having the greatest value for the least expenditure. Accommodating greater flood magnitudes necessitates larger, higher, and/or more-massive structures and therefore, usually, a greater expenditure. An increase in extreme flood flows owing to climatic change affects the size and robustness of the infrastructure needed to accommodate increased flows.

The design of infrastructure should be related to an inherent risk of failure during its design life. Guillard (2006) states that the major impact of climate change on hydraulic structures will be an unavoidable increase in the construction cost of the projects and on the cost of the services provided. Reliable estimates of the costs associated with infrastructure being exceeded by flows at specified frequencies would allow the design flow to be selected primarily based on project economics—often in terms of net benefit or a benefit-to-cost ratio—but such a detailed approach is often not practical.

In many cases, the design flood frequency for a given type of hydraulic structure has been based on precedent. The design values used have evolved over time from experience, which might or might not be enacted in engineering codes and standards or legislated. Climate change may render this approach invalid, as past events might not be representative of future flood potential. There is evidence that the hydrological regime in parts of the Atlantic region is not stationary and will continue to change in the future (R.V. Anderson 2008). Adaptation to climatic change requires consideration of potential increases in design floods.

Bourque and Simonet (2006) see an important role for engineers in climate change adaptation. Since socioeconomic vitality strongly relies on infrastructure and the work of engineers, they state that upcoming impacts justify a review of how engineers integrate climate information with respect to the life cycles of infrastructures. To meet the climate change challenge, Engineers Canada and its partners formed the Public Infrastructure Engineering Vulnerability Committee (PIEVC), which developed the PIEVC Engineering Protocol for Climate Change Infrastructure Assessment as a step-by-step process to assess the impact of a changing climate on the performance, reliability, and durability of infrastructure (Engineers Canada 2007).

Climate Change

Climate change will affect hydrological systems, as precipitation is the main driver of variability in the water balance over space and time (IPCC 2001b). Climate change will alter the hydrologic response of watersheds; for example, an increase in rainfall will increase total runoff, a change in mean rainfall and/or temperature will change soil moisture conditions, and changes in seasonal and daily temperature regimes will affect the amount and form of precipitation, the amount of snowfall, and the amount and timing of snowmelt runoff. Climate change cannot be mitigated totally and is expected to continue throughout the 21st century (IPCC 2001a).

Climate change is making hydrological conditions more extreme in some regions. There is some evidence of an increase in the frequency of “large” floods (IPCC 2007). Arora and Boer (2001) found that an increasing amount of precipitation in middle-latitude river basins was falling as rain rather than snow and that spring runoff was occurring earlier. Based on growing evidence, there is high confidence that increased runoff and earlier spring peak discharge is occurring in many snow-fed rivers (IPCC 2007). Increased break-up events under enhanced melt conditions could result in significant ice jamming, which can, in turn, result in severe flooding (Prowse and Beltaos 2002). Therefore, climatic change poses a danger of increasing catastrophic floods due to earlier break-up of river ice and increased probability of heavy rain in Atlantic Canada. Human adaptation to altered hydro-climatic conditions is necessary, and adaptive strategies that lessen the potential for adverse effects must be developed and implemented.

Swansberg et al. (2004) provide an indication of the direction of changes in climate and river discharge in New Brunswick. They used statistical downscaling to project changes in temperature, precipitation, and river flow at several locations in the province, assuming a tripling in carbon dioxide (CO2) over pre-industrial levels—hopefully the worst-case scenario. By downscaling river flow, the authors found that average annual discharge would increase significantly at the seven hydrometric stations they considered. As the distribution of hydrologic changes was not projected to be uniform throughout the year, changes in peak flow would likely increase more than mean annual flow.

R.V. Anderson (2008) found trends in hydrologic data were beginning to appear in the hydrometric records at 12 hydrometric stations in New Brunswick, with climate change and variability the most plausible explanation. They found that the dates of spring flooding have advanced earlier in the year, although the magnitude of flood peaks generally was trending lower, except for stations in southeast New Brunswick. Straight linear extrapolation of trends will not necessarily provide accurate estimates of future hydrologic conditions.

Lines et al. (2008) made projections for 14 sites in Atlantic Canada of future total daily precipitation using the statistical downscaling model (SDSM) and predictors based on two General Circulation Models (CGCM2 and HadCM3) and SRES emission scenario experiment B2. Downscaled projections of precipitation were found to be greater than CGCM2 output values, thereby seemingly indicating regional influences on climate. Overall values of extreme precipitation amounts were found to increase with each return period.

Inland flooding can also result from poor drainage. Potential increases in heavy precipitation, with expanding impervious surfaces, could increase urban flood risks and create additional design challenges and costs for storm-water management (Kije Sipi Ltd. 2001). Climate change is expected to affect storm-water design calculations as the intensity and frequency of heavy rainfall events increases, and through changes in the antecedent moisture loading of soils and water storage (Shaw et al. 2005). Coulibaly (2006) found that IDF curves based on downscaled data (current and future climate conditions) revealed changes in the precipitation intensity between the current and the future time periods for sites in Ontario (2050s and 2080s) for the different durations and return periods considered. The expected change of rainfall in design storms can be incorporated into design calculations and hydrologic modelling, but evaluation of rainfall characteristics may be required for larger catchments with varying topography or drainage features (Shaw et al. 2005).

Drainage regulations should be upgraded, taking into account revised national standards. While the provinces should become and remain proactive in the area of stormwater management, drainage issues must be dealt with locally (Kije Sipi Ltd. 2001). When the City of Peterborough, Ontario, experienced two "100-year flood events" within three years, it responded by flushing the drainage systems and replacing the trunk sewer systems to meet more extreme 5-year flood criteria (UMA Engineering 2005 [Hunt 2005, as reported in IPCC 2007]). Arisz and Burrell (2005) state that the best approach to accommodate the effects of climate change on municipal drainage infrastructure is to use piped (minor) and overland (major) drainage systems, and to incorporate potential future capacity requirements of the major drainage system early in the design and planning process.

CHALLENGES, BARRIERS, GAPS, AND NEEDS

Challenges

The challenges in adapting flood damage reduction to climate change are often more social, political, and economic in nature than scientific. Why did past flood management efforts, particularly under the Flood Damage Reduction Program (FDRP, see Appendix A), not lead to substantial reductions in flood damage? The problem did not arise from gaps in scientific knowledge about inland flooding or a lack of techniques and tools to define flood hazard areas. Rather, it arose from socio-political considerations that limited the amount of support for flood damage reduction efforts and flood management initiatives. Once an area was mapped and designated as a flood risk area under the FDRP, provincial governments were to encourage the adoption of flood-plain zoning by municipalities and local zoning authorities to restrict activities in those areas. Provincial governments were also to instruct government agencies and the private sector to restrict their funding of new developments in flood risk areas.

Placing restrictions on landowners and developments did not provide benefits to incumbent politicians, who were far more likely to support more flood forecasting and flood compensation activities that did not address the potential for future flood damages. Shrubsole (2000) states that senior governments provided neither consistent nor strong signals on the need to truly integrate structural and non-structural adjustments to reduce flood damages, and therefore, understandably, many municipalities generally limited their support for and actions on flood-plain regulation and land use controls. Political will is essential for achieving effective cooperation and coordination among all involved groups implementing a flood management strategy (Burrell et al. 2007).

An additional major challenge is insufficient data and data collection. Reliable climatic and hydrologic information (streamflow, snow cover, soil moisture) is essential for the modelling and other analyses required for flood forecasting and warning, flood area delineation, and infrastructure design. Restoring and retaining adequate data collection networks and the timely distribution of accurate time-series data is a challenge faced by many data collection agencies, especially during times of governmental fiscal restraint. Apart from routine collection of baseline data, government departments often lack the human and financial resources to collect basic information on the physical characteristics of a flood event as it occurs—information that can be extremely valuable in advancing the understanding of flood behaviour.

Another challenge is the lack of direction and coordination in flood management activities and climate change adaptation with respect to floods. Each agency tends to operate within its specific mandate. Although several government agencies may be involved with forecasting, flood fighting, or emergency measures during a flood, there is often no assigned agency or sufficient resources allocated to collect, collate, evaluate, retain, and publish the information after the event so that it can be of practical use to researchers, disaster planners, and environmental and natural-resource professionals.

Challenges cont'd

There is also a challenge in making climate change projections acceptable to the public and decision makers, and amenable to adaptation. A scientific approach that considers a wide range of emission scenarios and hypotheses can impair public acceptance and be an impediment to decision making. If greatly differing results can be obtained depending on the approach, model, or emission scenario considered, the logical choice may be to pick the result most favourable to specific interests or points of view. Adaptation has to focus more on identified problems likely to occur and on acceptable (but not necessarily optimal) solutions to these problems. This can be facilitated by identifying (subject to scientific judgment and periodic review) the models and scenarios, and thus the climate change projections, deemed most applicable for Atlantic Canada.

Another challenge is to develop a program of affordable flood insurance for persons wishing to purchase such protection. Although flooding is one of the most significant causes of disasters in Canada, insurance for losses incurred from overland flooding is not generally available for private homeowners. More comprehensive flood insurance in Canada will not be possible unless appropriate risk assessments are in place and a partnership developed between government, the insurance industry, and private homeowners (Sandink et al. 2010).

The FDRP Legacy and Current Implications

Under the Flood Damage Reduction Program (FDRP), flood-prone areas in Atlantic Canada were mapped, zoning authorities were encouraged to consider flood hazard, and financial incentives and disincentives were established. The federal minimum criterion for defining a flood risk area under the program was the 100-year flood (a statistically determined hypothetical flood that has one chance in one hundred of being equalled or exceeded in any given year). The limits of past flood events were sometimes used (the 1973 flood along the Saint John River in New Brunswick, for example), providing that they were greater than the 100-year flood. Floodways were usually based on the 20-year flood. Considerable effort was exercised in the production of the FDRP flood risk maps, and they remain a valuable source of information on flood hazard in several communities in Atlantic Canada.

Since most of the flood risk mapping under the FDRP was done, there have been improvements in readily available flood models and major advances in surveying and mapping methods. Furthermore, additional data have become available for use in estimating flood flows and in calibrating and verifying models. More-recent data possibly shows a shift toward higher flows. Depending on the characteristics of flooding within the river basin, there could be changes from previously determined flood levels derived from models. These changes would likely be more significant in areas where data were limited for previous studies, and more important for areas with mildly sloping flood plains and where flood risk areas were determined based on modelling approaches rather than documentation of past flood events. Combining this information with a need to update cultural information on some maps, we conclude that there is currently a need to update the flood risk mapping for several communities.

Knowledge Gaps

The process for selecting suitable flood management options for a given area starts with a review of available information and data related to the river system and area to be protected from floods. For many locations, unfortunately, this information is often unavailable, insufficient, inaccurate, or outdated. There is a need to locate, recover, and retain past flood reports and supporting documents (including historical accounts and reports produced under the FDRP), to develop databases on past flooding (if none exist), and to develop strategies for ongoing collection of flood information.

Although considerable modelling software exists to define flood-hazard areas, basic information is often missing to properly set up, calibrate and verify the models. Such information includes design flows, physical dimensions and flow-conveyance properties of channels and flood plains, rational upstream and downstream boundary conditions, and observational data from high-water events.

Event monitoring refers to documenting a flood event, including its causes, physical characteristics (timing, duration, peak flows, water levels over time, areal extent), and associated impacts (ecological, social, economic, negative and positive). Information on flood characteristics is needed for numerical model calibration and verification. Information on causes and flood benefits and damages is useful for developing flood mitigation strategies, flood damage reduction measures, and flood hazard awareness / public information campaigns. To facilitate event monitoring, guidelines for flood monitoring, documentation, and reporting could be developed for Atlantic Canada.

Research Needs

Much of the fundamental research on flooding was carried out during the latter half of the 20th century, resulting in major advances in the understanding of hydrologic response, watercourse hydraulics, and ice-jam processes. As a result, fundamental research on flood mechanisms is likely to become less important than applied research aimed at interpreting flood information and developing means to cope with anticipated flood problems.

For the purpose of infrastructure design, a great need exists for applied engineering research—specifically on the development of design storms and methodologies to incorporate climate change considerations in design flow estimation. It is currently very difficult to translate climate change theory into engineering practice because much of the existing research has not been oriented toward practical applications. For example, the relationships between flood damages and flood velocity and duration could be investigated to see if there is a need to give these factors more attention in engineering design (such as the choice of building materials).

Although climate change is unlikely to affect fundamental mechanisms, it is likely to alter the hydrologic inputs, leading to greater or lesser flood occurrence and severity. Therefore, climate change is a very important factor to consider in applied flood research. To date, only a few rivers have been studied in detail, and extrapolation of results to other river basins is not straightforward; river and flood-plain characteristics, land use, and water management may differ from one to another. It is unrealistic to expect that scientific research will eliminate uncertainty in climate change projections and future inland flooding; elaborate scientific investigations with this objective are not necessarily productive or beneficial. However, climate change research aimed at defining factors that will change the flood behaviour within basins is needed.

There is a need for better tools to predict and mitigate flash flooding. The December 2010 flood events in the Maritimes provided evidence of this need. The process to identify hazard areas is similar to that used for riverine flooding, but the delineation of flood-prone areas may be less precise because of uncertainties in flow patterns and obstructions. Changes in rainfall intensity and volume arising from climate change may be an important factor in the severity of future flash flooding.

There is also a need for socio-economic and legal research. As governments try to cope with the potential for increasing future flood damages resulting from climate change, an analysis of public response to past flood events and efforts at flood risk management would help to reveal problems that could arise. Legal research on flood legislation could be carried out to examine the compatibility of flood plain legislation and flood hazard zoning with environmental legislation.

CURRENT PROJECTS AND ACTIVITIES

This section provides a brief overview of existent or imminent applied projects, university or other research, government legislation, policies, and plans or commitments.

Atlantic Canada: New Brunswick

Several studies related to climate change adaptation have recently been funded under New Brunswick's Environment Trust Fund (ETF). These projects cover a broad range of activities, from public meetings to technical studies. A few of the ETF projects relate to flood hydrology. In 2008, a hydrologic trend analysis revealed a trend toward earlier spring flooding (R.V. Anderson 2008). Recently, to update a previous (1987) flood-frequency analysis for New Brunswick, hydrological analyses used historical data from 56 hydrometric stations (Aucoin et al. 2011). The study results were found to be consistent with those from earlier studies, although updating the flood information resulted in an improvement of flood estimates for some hydrometric stations. In early 2011, a study was completed on the impact of climate change on the discharge regimes in New Brunswick rivers (Turkkan et al. 2011). The hydrological responses of seven catchments to two emission scenarios were simulated using an artificial neural network (ANN). Future high flows were estimated by the introduction of a Regional Climate Index (RCI) in New Brunswick, and it was found that the frequency analyses would most likely increase by 11–21 per cent toward the end of the century, depending on the emission scenario.

The North Shore Micmac District Council, representing several communities in northeastern New Brunswick, have carried out an investigation that identified several adjustments in land use that would have to be made as a result of projected climate change effects on coastal and inland flooding (Cox, 2011).

The New Brunswick Departments of Environment and Public Safety are developing options for improved policy on flood damage reduction (Whyte, D., 2011, personal communication).

Newfoundland and Labrador

Newfoundland and Labrador already has a flood-plain land use policy (Newfoundland and Labrador, Department of Municipal Affairs 2009). Following severe flooding in recent years, flood risk mapping work was renewed in Newfoundland and Labrador. For example, extensive flooding took place in Stephenville and surrounding areas in September 2005, and there have been physical changes to the watercourses, including sedimentation and erosion, since the time of a 1996 hydrotechnical study. A consulting firm was consequently retained in December 2008 to update the hydrotechnical information[1]. In March 2011, terms of reference were issued and a request for proposals made for a Flood Risk Mapping Project for Logy Bay-Middle Cove-Outer Cove, NL, by the Department of Environment and Conservation. The study is to be completed by the end of February 2012.

1. Hatch (a consulting firm) in December 2008 was asked by the Newfoundland and Labrador Department of Environment and Conservation to update the hydrotechnical information as it relates to Blanche Brook and its two tributaries, Warm Creek and Cold Brook, Stephenville, Newfoundland and Labrador. Analyses to complete the flood risk mapping involved hydrological, hydraulic, and sensitivity analyses. The hydrological component of the study involved the estimation of the 20-year and 100-year return period design flows using statistical analyses and deterministic modelling conducted using the computer software HEC-HMS. The output from the hydrological analysis was input to the hydraulic model HEC-RAS for determination of the response of the river reach to the hydrological inputs. Flood risk mapping was developed using the water levels determined using the HEC-RAS model based on the flows determined from the HEC-HMS model.

Interprovincial

In 2008, an Atlantic Adaptation Strategy was agreed to by the Council of Atlantic Environment Ministers. A work plan for an Atlantic Climate Adaptation Solutions initiative was submitted by the four Atlantic provinces to Natural Resources Canada for cost-shared funding under the federal Regional Adaptation Collaborative (RAC) program. The resulting initiative is a two-year, $8.2 million project aimed primarily at helping municipalities prepare for the potential impacts of climate change. Projects addressing issues common to the four Atlantic provinces were identified, including inland flooding and vulnerability assessments for communities in the lower Saint John River valley and Greater Moncton, NB, Stratford, PEI, Bay Roberts, NL, and the Halifax Regional Municipality, NS. These projects will examine how increased precipitation and flooding will affect infrastructure and land use, and they will provide a range of applied recommendations. Digital elevation data have been acquired for use in managing land use and development in relation to many of these projects.

The Atlantic Climate Adaptation Solutions Association (ACASA) was established to manage the Atlantic RAC program. This collaborative association of the four Atlantic provinces focuses on advancing climate change adaptation in the region. Several projects have been recently completed or are currently underway. For example, in New Brunswick, consultants have been engaged to evaluate the effects of sea-level rise and climate change scenarios on flooding and municipal infrastructure along the Petiticodiac River in the Moncton-Dieppe-Riverview area. A series of papers produced during the first quarter of 2011 (including this paper on inland flooding) explore and summarize important climate adaptation topics and themes.

Canada

The Institute for Catastrophic Loss Reduction (ICLR) was established by Canada's property and casualty insurance industry as an independent, not-for-profit research institute affiliated with the University of Western Ontario. In the past few years, ICLR partnered with Swiss Re to study flood management in Canada, focusing on reforms required to make susceptibility to floods insurable in Canada. ICLR researchers are also engaged in research that encompasses many aspects of home safety and consumer behaviour. ICLR investigated disaster resilience in local communities through developing long-term strategies for community disaster resilience and long-term strategies for flood mitigation, with a focus on urban flooding, basement flooding, and sewer backup (ICLR 2008).

The Insurance Bureau of Canada is overseeing a project to develop and test a Municipal Risk Assessment Tool (MRAT). The project is examining the application of a municipal storm-water model in an effort to better understand and manage flood risk in cities, especially risk from sewer overload and backup resulting from heavy precipitation. Fredericton, New Brunswick, was one of several centres taking part in the project, which is expected to expand to additional centres during 2011

CURRENT PROJECTS AND ACTIVITIES *cont'd*

Foreign: United States

In the United States, the Federal Emergency Management Agency (FEMA) administers the National Flood Insurance Program (NFIP), a major program with respect to flood damage reduction efforts. NFIP has well-established and somewhat rigid procedures and differs in philosophy and approach from those previously adopted in Canada under the Flood Damage Reduction Program.

In 2007, the Association of State Flood Plain Managers (ASFPM) prepared the report National Flood Policies and Programs in Review—2007 with the aim of identifying ways in which US policies and programs for reducing flood damage and protecting flood plains could be improved (ASFPM 2007). The report concludes that the top-down model used by the United States for managing flood risk over the past 75 years has achieved only marginal success. It also stated that techniques for minimizing and avoiding flood damage are well known, have been proven effective, and are constantly being improved, but the means by which these techniques are delivered and implemented (in the US) leave much to be desired.

The struggle to introduce more local control over flood-plain management in the United States is worth monitoring, but significant advances in flood damage reduction are being made elsewhere.

Europe

A summary of current practice in the development and management of flood research programs in various European countries was compiled and good-practice guidelines developed for identification, promotion, and validation of flood research programs (ERA-NET CRUE 2007). It provides suggestions and opportunities for program development and organization.

In 2007, the European Parliament and the Council of the European Union passed a directive on the assessment and management of flood risks, commonly known as the "Floods Directive" (EU Parliament 2007). The Floods Directive requires EU member states to assess potential flood effects on human health and life, the environment, cultural heritage, and economic activity. Areas identified to be at significant risk will then be modelled to produce flood hazard and risk maps by December 2013. The maps are to include detail on the flood extent, depth, and level for three risk scenarios: high, medium (likely return period ≥100 years), and low probability (extreme) events. This information will be used to form flood risk management plans that are to be implemented by December 2015.

Flood risk management plans are to address all aspects of flood risk management, including prevention, protection, preparedness, and flood forecasts / early warning systems, while taking into account the characteristics of the particular river basin or sub-basin (EU Parliament 2007). The Floods Directive states that development of river basin management plans and flood risk management are elements of integrated river basin management and that the two processes should therefore result in common synergies and benefits, while considering environmental objectives (as per Directive 2000/60/EC), and ensuring efficiency and wise use of resources. As a result of the Floods Directive, considerable work on flood damage reduction is underway in Europe, and this may provide new insights for flood damage reduction elsewhere.

Conclusions and Recommendations

The underlying concepts—of identifying, mitigating, and avoiding flood hazards—that constitute the basis of flood damage reduction are generic and do not necessarily depend on specific hydro-climatic conditions. To protect public safety and reduce flood damages, the basic steps are to define the hazard, ascertain its extent, and take action to mitigate its potential magnitude and severity. This is the case whether considering future or present climates. In the case of human settlement and development, this means avoidance and/or measures to reduce susceptibility to floods. Flood damage reduction measures do not have to be re-invented for climate change.

Sufficient information exists from trend analyses and climate change projections to state that human activities are influencing climate change. Although some uncertainty remains as to the magnitude of change, the direction of change is becoming clearer, thereby providing increased impetus for adaptation to reduce vulnerabilities to climate-related flood damages. Coordinated efforts are needed to initiate new adaptive strategies and carry out flood management measures to build adaptive capacity. To address flood hazards expected to become greater and more frequent than in the past, new collaborative efforts and partnerships—which do not adhere to jurisdictional boundaries and which may not accord with present agency mandates—may be necessary.

Opportunities exist in Atlantic Canada to take action to protect the safety and health of Canadians, private property, and public infrastructure from the potentially detrimental effects of inland flooding under the influence of climate change. Using the legacy of information provided through the Flood Damage Reduction Program, flood management strategies can be developed to reduce both present and future vulnerabilities to inland floods. The ability to adapt will depend significantly on political will to provide direction and effective government action, incorporating a mix of structural and non-structural flood damage reduction measures. To provide essential support, collaboration must be fostered among professional associations, municipal governments, community leaders, businesses, and voluntary-sector organizations.

Planners need to consider flood hazard in directing new development, while maximizing the benefits of flood plains and treating property owners in a fair and equitable manner. To do this, they need to be aware of developments in socio-economic and legal research relative to urban planning and flood hazard delineation, zoning and land use controls—as well as the influence of climate change.

Engineers need new and updated climatic design values, revised codes and standards, and new methodologies to incorporate into engineering procedures when current infrastructures are upgraded and replaced. Design codes and standards, as they are rervised, should incorporate consideration of the greater and potentially more damaging flood events expected under future climate scenarios; it is important that undersized infrastructure does not worsen future floods and that failure or damage of infrastructure does not increase future flood damages. Nevertheless, design codes and standards must be pragmatic, taking into account economic and technological feasibility, and new methodologies must be practical, taking into account data limitations and the likelihood of client support for a design engineer's time and effort.

Recommendations are as follows:

1. Governments, communities, and individuals should maintain and enhance current measures and programs to protect property from flood-related damages and incorporate climate change information into existing activities and planned future developments.

2. Clear guidance should be provided as to the preferred models and scenarios to consider in climate adaptation planning.

3. Data collection should be enhanced where necessary. An increase in modelling capability has not eliminated the need for good input data. Technology cannot be used as a substitute for information. A robust climate-observing network must be retained, and hydro-climatic design parameters and design flood events should be updated frequently as the climate continues to change.

4. Hydrometric networks should be maintained and enhanced, as the detection of trends depends on the availability of good multi-decadal hydrometric records. Stations on natural-flow rivers with more than 30 years of record should be especially maintained and protected as integral elements of the hydrometric network. Elimination of the present gaps in hydrometric coverage, including those on smaller watercourses, should be considered.

5. To facilitate flood event monitoring, it is recommended that a minimum set of guidelines for future flood monitoring, documentation, and reporting be developed for Atlantic Canada.

6. A minimum standard flood, expressed in terms of annual exceedence probability, should be adopted for planning new structural and non-structural flood mitigation measures in Atlantic Canada[2].

7. Flood-damage-reduction strategies that consider climatic change should be developed. The focus should remain on the reduction of inland flood damages and protection of flood-plain functions (both present and future). Flood damage reduction efforts should not be distracted by the uncertainties of climate change projections or technology, as information and approaches may change periodically. The focus on damage reduction should stay the same.

8. Professional-development opportunities for planning and design professionals should be increased. The aim should be to empower these professions to move from awareness of climate change effects to routinely incorporating climate change adaptation into their practice[3].

[2] The basis of risk-area delineation could be the 1 per cent annual exceedence level used in the Flood Damage Reduction Program. In the case of critical infrastructure, such as hospital and emergency service buildings, the minimum standard could be increased to the 0.5 per cent annual exceedence level or largest historic flood level, whichever is greater.

[3] The Workshop "Guidelines for Floods and Droughts in New Brunswick. 2010-2100" held at the Wu Conference Centre on March 17, 2011, is an example of the provision of practical information and techniques on specific topics, as needed by practising engineers and water managers. [Online.]
http://www.umoncton.ca/hydro/files/hydro/wf/wf/pdf/WorkshopAgenda.pdf (accessed February 5, 2012).

LINKAGES AND KEY RESOURCES

In Atlantic Canada, considerable capability exists with respect to flood studies and flood mitigation. Expertise can be found in the academic, government, and consulting communities.

Appendix B identifies several of the more important researchers, research groups, and consultants doing work on inland flooding and climatic change. High-level contact information is provided where available.

APPENDIX A:

The Flood Damage Reduction Program

General

Initiated in 1975 to curtail escalating disaster assistance payments and disruptions to the national economy, the Flood Damage Reduction Program (FDRP) was to discourage future flood-vulnerable development (Environment Canada 2010). The FDRP was carried out under cost-shared federal-provincial agreements. Normally, a general agreement outlining the policies of the program was supplemented by subsidiary agreements on mapping and other additional flood-related work. For example, sub-agreements have covered flood forecasting in New Brunswick, structural implementation in New Brunswick, and flood studies in New Brunswick and Nova Scotia. Variations existed on how the agreements were drawn up.

Under the program, a flood risk area was defined as a flood-prone area based on the mapped limits of an identified flood risk that federal and provincial government ministers had declared officially as a flood risk area by approving and signing appropriate documentation. Once a flood risk area was mapped and designated, both the federal and provincial governments agreed not to build or support any future flood-vulnerable development there. The designation was considered "final" if minimum mapping and hydrotechnical specifications were met but "interim" if these standards were not met. New development built in a flood risk area after designation was not to be eligible for disaster assistance in the event of a flood unless certain conditions were met.

The flood risk area often was defined using floodlines derived by the completion of hydraulic/hydrodynamic studies using the 100-year-return-period flood flow estimate as input. A 100-year peak flood flow is the statistically determined flood event, usually derived from frequency analyses of past hydrometric records, that has one chance in one hundred of occurring in any given year, given a long period of record. The probability is the inverse of return period, so the 100-year flood has a 1 per cent chance of occurrence in any given year over a longer period. The federal minimum criterion for defining the flood risk area was the 100-year flood, but more stringent provincial criteria were sometimes adopted. For example, the flood risk areas from Fredericton to Lower Jemseg were designated on the basis of the extent of the 1973 flood, which had higher flood levels than the derived 100-year flood.

The 100-year-flood flows for the purposes of flood damage reduction were often derived based on annual maximum instantaneous flood flows, which takes the highest flood per year and ignores the second-highest peak flow, although that flow could be higher than the maximum flood flow in other years. An alternative approach to this block maxima approach is to perform frequency analysis on all flood flows over a certain threshold—the peak-over-threshold (POT) approach.

The Flood Damage Reduction Program cont'd

The designated flood risk areas were often subdivided into two zones: the floodway and the flood fringe. The floodway was the portion of the flood risk area with greatest flood depth and velocities and the greatest potential for flood damage. Developments in the floodway could endanger human life and damage to property and act as obstructions to flood conveyance, thereby increasing flood levels upstream. Therefore, most types of development in the floodway were discouraged. The floodway was usually defined on the basis of the 20-year-return-period flood (determined following a similar procedure as per the 100-year flood). The remainder of the flood risk area, between the floodway and the outer limit of the flood risk area, was called the flood fringe, or floodway fringe. Within the floodway fringe, several types of development were considered acceptable. Flood-proofing measures were to be incorporated into the design and construction of most buildings built in the floodway fringe if they were to receive financial support under government programs.

Two types of flood risk maps were produced: large-scale topographic (engineering) maps, usually at scales of 1:1000 to 1:5000, that accurately delineate the flood risk area, and smaller-scale (public-information—usually planimetric) maps, with scales ranging from 1:5000 to 1:50,000 that show the approximate location of a flood risk area and provide the public with information on the Program. Both types of maps display the designated flood risk area, the floodway, if determined, and occasionally the extent of historic flood events.

Environment Canada's Flooding: Canada Water Book (Andrews 1993) provides an overview of flooding in Canada and an introduction to flood damage reduction and assistance programs. It discusses the evolution of government involvement with flood damage reduction leading to the Flood Damage Reduction Program and the basic philosophy of the program.

Mapping and Hydrotechnical Study Standards

Hydrologic and Hydraulic Procedures for Flood Plain Delineation was developed as a guide for hydrologic and hydraulic investigations carried out under the Flood Damage Reduction Program to produce flood risk maps (Environment Canada 1976). It is stated that the most important piece of information on any flood risk map will be the lines that define the area inundated by the designated flood. The flood that defines the flood risk area could be based on probability, a specified input, or a large recorded flood. Furthermore, other floods smaller in magnitude than the designated flood could be mapped, and hydrologic and hydraulics analyses may be required when the flood lines are not shown on mapping, as per the design of flood control works. A flood based on probability must be determined by a frequency analysis of recorded flood peaks and should be the best estimate for the required probability of occurrence.

Hydrologic and Hydraulic Procedures for Flood Plain Delineation contains a discussion of the data required for hydrotechnical studies. A considerable amount of information from numerous sources is needed to determine the water-surface elevations corresponding to peak flood flows. Required data often include streamflow records and information on flow regulation if applicable, historical flood information and high-water marks, snowmelt and precipitation information, stage-discharge relationships, channel and flood-plain cross-sections, and dimensions of waterway openings at hydraulic structures. In addition, there will be a need to determine hydraulic parameters and boundary conditions from field inspection, mapping, and aerial photographs.

Mapping and Hydrotechnical Study Standards cont'd

One of the main steps in flood risk mapping is the determination of the desired flood magnitude. For many water-resource projects in the past, crude hydrologic estimates were employed, but for the flood damage reduction program, a higher standard of hydrologic analysis was required (Environment Canada 1976). In particular, proposed procedures were intended to ensure valid flood-frequency analyses. Guidance was also provided on conversion of regulated to natural flows and extension of streamflow records.

In Hydrologic and Hydraulic Procedures for Flood Plain Delineation, it is stated that single-station flood-frequency analysis will be adequate only if the streamflow record is long and reliable. If the record is not of sufficient length (say 30 to 40 years) or if there is some doubt about data reliability, a regional flood frequency analysis is recommended. A regional analysis requires the definition of a homogeneous region based on basin characteristics, and is thus more time consuming. A technique (index flood method, multiple regression analysis, or determination of regional distribution parameters) then must be chosen to develop regional relationships from the results of single-station frequency analyses. The second step in flood risk mapping is the determination of the floodlines. Hydrologic and Hydraulic Procedures for Flood Plain Delineation contains a discussion of hydraulic modelling requirements. The chosen model should be capable of handling the types of flow encountered in the watercourse, performing critical depth computations, allowing addition of interpolated cross-sections, and allowing differing hydraulic parameters as input. It is advantageous to use a computer model that has the ability to use known high-water marks to calculate the roughness coefficients. (Since the guidelines were published there has been considerable progress in model development, with modern models such as HEC-RAS and MIKE11 having the capabilities mentioned in the report.)

Hydrologic and Hydraulic Procedures for Flood Plain Delineation also refers to the difficulty of estimating the effects of ice jams and debris jams on floods of a given magnitude. Combined frequency analyses can be performed to get an estimated stage frequency associated with an ice jam, and ice jams can be modelled in various subroutines of some of the more advanced computer models presently existing. Despite the major technological advances in river ice science and engineering (see Beltaos 1995), and in the understanding and modelling of river ice jams, the determination of ice-jam floodlines remains difficult, mainly because little information on past ice jams and ice regimes exists for many rivers.

The last section of Hydrologic and Hydraulic Procedures for Flood Plain Delineation deals with reporting requirements. The technical report has to include information on flood magnitudes and types, a summary of data used in the analyses, a description of the hydrologic and hydraulic methodology, and a complete description of techniques used that were outside the guidelines. Of particular importance is the provision of data (with explanatory notes), both measured and estimated, that were used in hydrologic modelling and information on model verification, whereby recorded events independent of those used for model calibration are reconstituted. In hydraulic modelling, it is important to include a brief explanation of each aspect of model operation and to differentiate between estimated and measured parameters (Environment Canada 1976).

New Brunswick was the first province to join the Flood Damage Reduction Program, signing general, mapping, and studies agreements in March 1976. Over the next two decades, 13 flood risk areas were mapped and designated. A sub-agreement on structural controls centred on building sea dykes in the Petitcodiac area. A studies sub-agreement funded ice research on the Restigouche River and the international section of the Saint John River.

The Flood Damage Reduction Program in Atlantic Canada cont'd

Before 1972, flood forecasting was done on the Saint John River by the New Brunswick Department of the Environment in cooperation with the New Brunswick Electric Power Commission. In 1973, these two agencies, with assistance from the federal government, combined their efforts to develop a more sophisticated flood forecasting system for the river. In 1977, the Canada–New Brunswick Agreement Respecting Flood Forecasting was signed. The sub-agreement on flood forecasting helped the province establish a flood forecasting centre for the Saint John River, including the required technology development and transfer. The River Forecast Centre (RFC), now the hydrologic services component of the New Brunswick Department of Environment, forecasts river levels along the Saint John River and its main tributaries below Fredericton where the major flood damages are experienced in the province. (Recently this service was extended to upstream reaches of the Saint John River.) This service is provided during the spring freshet as well as occasionally at other times of year following heavy rainfall. The flood forecasting agreement also provided for setting up a flood warning system, manned by volunteers and municipal staff, for the Kennebecasis River.

A separate agreement (outside the general agreement) was negotiated with the federal and provincial governments and the city of Saint John for flood control in the Marsh Creek area. Each party assumed one third of the costs. The works included channel improvements, improvements to outlet control structures, a new reservoir, and reconstruction of a bridge.

Nova Scotia joined the Flood Damage Reduction Program in 1978, signing a general and a mapping and studies agreement. The 100-year flood was used to delineate and designate flood plains in nine communities, which have all incorporated the mapping in their land use bylaws. The two-zone approach has been used where future development is prohibited in the floodway, defined by the 20-year flood, but development is permitted in the flood fringe if adequate flood-proofing is carried out.

A flood damage reduction agreement was never negotiated with Prince Edward Island. The small watersheds and previous low losses to flooding did not justify one.

Newfoundland and Labrador joined the Flood Damage Reduction Program in 1981, signing general and mapping agreements and, two years later, a studies agreement. The province, with the federal government, worked to reduce the human hardship and economic loss of floods through the Canada-Newfoundland Flood Damage Reduction Program from 1981 to 1993. Sixteen areas were mapped and designated under the program, and remedial measures studies were carried out in four areas. From 1993 to 1996, further flood studies were carried out under the federal-provincial General Agreement Respecting Water Resource Management. This was a comprehensive agreement that included—along with flood damage reduction—groundwater management, watershed and water quality management, flow forecasting systems, water conservation economic studies, and estuary and aquaculture management studies (Newfoundland and Labrador, Department of Environment and Conservation 2011).

Flood risk mapping in Newfoundland and Labrador delineates the floodway as a zone where floods have a return period of 20 years (5 per cent chance in any year) and the flood fringe where the risk of flooding is once in 100 years (1 per cent chance in any year). Flood risk areas have been mapped for 38 communities in the province. Several hydrotechnical studies and flood risk maps are available online (Newfoundland and Labrador, Department of Environment and Conservation 2011).

APPENDIX B:
Contact Information

Disclaimer

All information provided in Appendix B is provided for information purposes only. Reasonable effort was made to present current and accurate information, but information in Appendix B is subject to change. Neither ASACA nor the consulting firm R.V. Anderson Associates Limited makes any guarantee of any kind that the list is complete or comprehensive, and assume any responsibility for the misinterpretation and misuse of the information presented.

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Dr. Chen's interests include watershed modelling and management, climate change and northern studies, and decision making under uncertainty.

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Dr. Snelgrove's research interests include planning for more damage-tolerant transportation infrastructure under the influence of climate change, and extension of rainfall-runoff models to non-point-source nutrient loading of surface waters.

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Dr. Catto's research interests include the impacts of climate change, fluvial geomorphology, and flood risk assessment. Dr. Catto is a member of the steering committees for the Canadian Climate Change Impacts and Adaptations Research Network (C-CIARN) node dealing with Atlantic Canadian issues.

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Dr. Hansen's general research interests include deterministic hydrology, rainfall- runoff modelling, urban drainage, statistical hydrology, river engineering, and open channel hydraulics.

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Dr. Cassie's main research interests are the thermal regime of rivers and river heat fluxes, stream temperature modelling, instream flow requirements, statistical hydrology (floods and droughts), river hydraulics, and anthropogenic impacts.

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Dr. Nassir El-Jabi, although occupying an adminsitraive post at the university, is one of Atlantic Canada's major contributors to the investigation of floods and climate change, often with Daniel Caissie and Andre St. Hilaire as collaborators.

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Dr. Laroche's areas of specialization include hydrology, hydrogeology, integrated management of the water resources by catchment area, and hydrological modelling.

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Dr. Bettignies' field of specialization is hydrology and the environment.

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Dr. Askar's area of specialization is statistics applied in hydrology and water resources, including forecasting and statistical modelling of extreme meteorological events, statistical analysis of risk and reliability analysis of time series, regressive models, multivariate analysis, regionalization of extreme meteorological events, and resampling for applied hydrology.

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Dr. Shrubsole's research interests include resource and environmental management, integrated water management, and policy implementations and evaluation. A recent publication is Shrubsole, D. 2007 From structures to sustainability: a history of flood management strategies in Canada. International Journal of Emergency Management 4(2): 183-6.

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Dr. Gordon McBean is a leading expert on climate change and its impacts and response strategies. He is the former Assistant Deputy Minister for the Meteorological Service of Canada and has worked with colleagues around the world on weather and climate. He is Chair of the Canadian Foundation for Climate and Atmospheric and Science and Chair of the hazard research program at the International Council for Science Union (ICSU). Recent and current projects include examination of weather storms, their impacts and their predictability; relationships between human health and weather; natural hazards research.

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Dr. Slobodan Simonovic is a leading expert on flood prevention and management issues. He has been very involved in risk and adaptation strategies around the world. He was a member of the International Joint Commission's Red River Task Force and is serving as an officer for a number of national and international water organizations.

Pacific Climate Impacts Consortium

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PO Box 1700 STN CSC
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http://www.pacificclimate.org/
[Last accessed: March 24, 2011]

Dr. Francis Zwiers

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Dr. Zwiers' research interests include:

- *climate variability and extremes*
- *climate predictability*
- *climate change detection*
- *ensemble simulations and statistical climatology*

Before becoming Director of the Pacific Climate Impacts Consortium, Dr. Zwiers served as a Research Scientist (1984-2006), Chief of the Canadian Centre for Climate Modelling and Analysis (1997-2006) and Director of the Climate Research Division (2006-2010), all at Environment Canada.

Environment Canada: Various Research Bodies And Locations

Heather Auld
Associate Director, Adaptation and Impacts Research
4905 Dufferin Street (next to AES HQ)
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Tel: (416) 739-4588 Fax: (416) 739-4297

Expertise: Climate, climate change and processes, adaptation and impacts, disaster management.

Brian N. Mills
Researcher and Applied Climatologist
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Research interests include evaluating the social and economic impacts of lightning, winter storms, and other weather or climate-related hazards.
Also Faculty of Environment, University of Waterloo (Waterloo, ON).

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Research Scientist and Study Leader, Climatic Impacts on Extreme River Ice Jams and Floods.
Dr. Beltaos' research includes ice breakup, ice jams, ice formation, and ice-related flooding. In Atlantic Canada, he has carried out projects involving Brian Burrell, Patrick Tang, Lindon Miller, and others.

Dr. Alain Pietroniro, PEng
Research Scientist/Hydrologist
National Water Research Institute (NWRI)
National Hydrology Research Centre
Saskatoon, SK

Research focus on implementation and design of hydrologic models and model components for applications development within the department. Other research interest include coupled atmospheric-hydrological modelling for climate change and land use change assessments on major drainage basins in Canada as well as couple numerical weather prediction models for flood forecasting and extreme event analysis, geomatics (remote sensing and GIS) applications for hydrology.

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Dr Arora's research interests include Earth's energy and water balance, interaction between the land and the atmosphere at large spatial scales, hydrological processes in general circulation models (including river flow routing), and the impact of climate change and variability on hydrology and water resources.

CONSULTANTS

Engineering Consultants

A few engineering consultants are listed below, but the list is not comprehensive. For more information, the provincial associations of engineering consultants (listed below) or provincial licensing bodies should be contacted.

AMEC Earth & Environmental

http://www.amec.com
500 Kings Road, Suite 208 Cabot House
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Tel: (902) 564-1110 Fax (902) 564-6318
Earth & Environmental
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Tel: (506) 458-1000 Fax: (506) 450-0829

AMEC is one of the world's largest engineering, project management, and consultancy companies.

The Sydney office specializes in environmental site assessments, risk assessments, and geophysical surveys.

The Fredericton office has a major focus on environmental planning and impact assessment and has been involved in environmental planning for several major capital projects in the Maritimes in recent years.

CBCL Limited

http://www.cbcl.ca
1489 Hollis Street, The Brewery
PO Box 606, Halifax, NS B3J 2R7
Tel: (902) 421-7241 Fax: (902) 423-3938
E-mail: info@cbcl.ca
Michael R. MacDonald, President
mikemac@cbcl.ca
Offices also in Fredericton, Saint John, Dieppe, Charlottetown, Sydney, St. John's, Cornerbrook, Goose Bay

CBCL Limited has a long-established history in the planning, design, and execution of development projects in the Atlantic provinces and in the planning and design of municipal infrastructure. CBCL staff are experienced in the water resources field and use computer simulation models such as OTTHYMO and HEC-RAS to assist them in stormwater and drainage control, flood-plain delineation, and hydraulic and hydrologic analyses.

HATCH

http://www.stantec.com
New Brunswick: Fredericton, Moncton, Saint John
Newfoundland and Labrador:
Clarenville, Corner Brook, St. John's
Nova Scotia: Halifax, Sydney

Hatch provides consulting, design engineering, technologies, environmental services, operational services, and comprehensive project and construction management.

CONSULTANTS *cont'd*

Engineering Consultants

R.V. Anderson Associates Limited

Offices in Fredericton, Moncton, and St. John's

http://www.rvanderson.com

For hydrotechnical projects, contact:

Mr. Hans Arisz, PEng

R.V. Anderson Associates Limited

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R.V. Anderson Associates Limited (RVA) has been engaged in the provision of professional engineering, operations, and management services since 1948. The organization comprises environmental and infrastructure specialists for water, wastewater, transportation, and urban development.

RVA's Fredericton office specializes in hydrotechnical engineering and the performance of infrastructure assessments.

STANTEC

http://www.stantec.com

Offices in several locations within Atlantic Canada

Stantec, founded in 1954, provides professional consulting services in planning, engineering, architecture, surveying, environmental sciences, project management, and project economics for infrastructure and facilities projects.

OTHER CONSULTANTS

Real Daigle

President

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379 Glencairn Drive

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Climatology, climate change science, climate change impacts.

Bill Richards

251 Bessborough Street

Fredericton, NB E3B 2Y5

Tel: (506) 455-7627

E-mail: william.richards@nb.sympatico.ca

Climatology.

Ouranos

550 Sherbrooke West, West Tower, 19th floor

Montreal, QC H3A 1B9

Tel.: (514) 282-6464 Fax: (514) 282-7131

E-mail: webmestre@ouranos.ca

Ouranos is a consortium that brings together 250 scientists and professionals from different disciplines. It focuses on two main themes: climate sciences and impacts & adaptation.

REGIONAL PROFESSIONAL ASSOCIATIONS AND SOCIETIES

Societies – Engineering Companies

Association of Consulting Engineering Companies of New Brunswick

The Association of Consulting Engineering Companies of New Brunswick (ACEC-NB) is a not-for-profit organization that seeks to improve the business environment for its member firms and their clients. Its website provides a list of member firms and information on hiring a consultant.

183 Hanwell Road, Fredericton, NB E3B 2R2
http://www.acec-nb.ca
Tel: (506) 470-9211 (506) 470-9211
Fax: (506) 451-9629
E-mail: info@acec-nb.ca
Executive Director, John Fudge PEng, MBA
www.acec-nb.ca/en/resources/
[Last accessed: March 24, 2011]

Consulting Engineers of Nova Scotia

The Consulting Engineers of Nova Scotia (CENS), formerly the Nova Scotia Consulting Engineers' Association, is a group of 50 Nova Scotia– based companies providing engineering and related services.

PO Box 613, Station M, Halifax, NS B3J 2R7
Tel: (902) 461-1325 Fax: (902) 461-1321
E-mail: cens@eastlink.ca
http://www.cens.org [Last accessed: March 24, 2011]

Consulting Engineers of Prince Edward Island

c/o Larry McQuaid, PEng
Delcom Engineering Ltd.
195 MacEwen Road, Summerside, PE C1N 5Y4
Tel: (902) 436-2669 Fax: (902) 436-8601
E-mail: lmcquaid@delcompei.com

Consulting Engineers of Newfoundland and Labrador

The Consulting Engineers of Newfoundland and Labrador is an organizations dedicated to the consulting engineering industry in Newfoundland and Labrador. Information is provided on its website of member firms.

PO Box 1236, St. John's, NL A1C 5M9
Tel: (709) 753-1014 E-mail: contact@cenl.ca
President: Richard Tiller, PEng
Tiller Engineering Inc.
Tel: (709) 579-6700 Fax: (709) 579-6701
E-mail: rtiller@tillereng.ca
http://www.cenl.ca
[Last accessed: March 24, 2011]

NATIONAL PROFESSIONAL ASSOCIATIONS AND SOCIETIES

Societies – Engineering Companies

Canadian Institute of Planners

141 Laurier Avenue West, Suite 1112
Ottawa, ON K1P 5J3
Tel: (800) 207-2138 or (613) 237-7526 (PLAN)
Fax: (613) 237-7045
http://www.cip-icu.ca
[Last accessed: March 7, 2011]
Executive Director: Mr. Steven Brasier CAE
sbrasier@cip-icu.ca
Planning for climate change web page:
www.planningforclimatechange.ca/wwwroot/dsp_HomePage.cfm
[Last accessed: March 7, 2011]

Representing a membership of approximately 7000 planning professionals across Canada, the Canadian Institute of Planners (CIP) has been dedicated to the advancement of responsible planning since 1919.

Canadian Environmental Law Association

130 Spadina Avenue, Suite 301
Toronto, ON M5V 2L4
Tel: (416) 960-2284 Fax: (416) 960-9392
Coordinator and Researcher: Sarah Miller
Tel: (416) 960-2284, ext. 213
millers@lao.on.ca
http://www.cela.ca
[Last accessed: March 24, 2011]

The Canadian Environmental Law Association (CELA) is a non-profit, public-interest organization using existing laws to protect the environment and advocating environmental law reforms. It has produced many publications on a variety of topics.

Canadian Meteorological and Oceanographic Society (CMOS)

PO Box 3211, Station D, Ottawa, ON K1P 6H7
Tel: (613) 990-0300 Fax: (613) 990-1617
Executive Director:
Ian D. Rutherford, PhD
Tel: (613) 990-0300 Fax: (613) 990-1617
E-mail: exec-dir@cmos.ca
http://www.cmos.ca
[Last accessed: March 23, 2011]

The Canadian Meteorological and Oceanographic Society (CMOS) is the national society dedicated to advancing atmospheric and oceanic sciences and related environmental disciplines in Canada. The society grants the status of CMOS Accredited Consultant to applicants who have demonstrated that they meet established standards of training and experience in the fields of atmospheric and oceanographic sciences.

NATIONAL PROFESSIONAL ASSOCIATIONS AND SOCIETIES *cont'd*

Societies – Engineering Companies

Canadian Water Resources Association (CWRA)

CWRA Membership Services Office
9 Corvus Court
Ottawa, ON K2E 7Z4
Tel: (613) 237-9363 Fax: (613) 594-5190
E-mail: services@AIC.ca
Executive Director: F.A. (Rick), Ross
1401 - 14th St. North Lethbridge, AB T1H 2W6
Tel: (403) 317-0017
E-mail: fjross@telusplanet.net
http://www.cwra.org
[Last accessed: March 23, 2011]

CWRA has the capacity to facilitate discussion among water users and water resource professionals. Members want to share their knowledge. CWRA activities are delivered through branch organizations in most provinces, and members are present throughout Canada and beyond. The Canadian Water Resources Journal is an important publication to Canada's water resources practitioners. The affiliated Canadian Society for Hydrologic Sciences (CSHS) represents CWRA members who are interested in hydrologic issues.

Engineers Canada

180 Elgin St., Suite 1100
Ottawa, ON K2P 2K3
Tel: (613) 232-2474 Fax: (613) 230-5759
Toll free: 1-877-408-9273
Chief Executive Officer:
Chantal Guay, PEng, MEnv
chantal.guay@engineerscanada.ca
Director, Communications and Public Affairs:
Marc Bourgeois
marc.bourgeois@engineerscanada.ca
http://www.engineerscanada.ca
[Last accessed: March 23, 2011]

Engineers Canada is the national organization of the 12 provincial and territorial associations that regulate the practice of engineering in Canada and license the country's professional engineers. It also coordinates the development of national policies, positions, and guidelines on behalf of the engineering profession.

NATIONAL PROFESSIONAL ASSOCIATIONS AND SOCIETIES *cont'd*

Societies – Engineering Companies

Canadian Society for Civil Engineering (CSCE)

The CSCE is a learned society intended to develop and maintain high standards of civil engineering practice in Canada and to enhance the public image of the civil engineering profession.

4877 Sherbrooke St. West
Montreal, QC H3Z 1G9
Tel: (514) 933-2634 Fax: (514) 933-3504
E-mail: info@csce.ca
Executive Director: Doug Salloum
Tel: (514) 933-2634 ext 24
E-mail: doug.salloum@csce.ca
http://www.csce.ca/About-CSCE
[Last accessed: March 7, 2011]

Committee on River Ice Processes and the Environment (CRIPE)

The Committee on River Ice Processes and the Environment derives from a working group established in 1975 by the Associate Committee on Hydrology (ACH), itself funded by the National Research Council of Canada (NRCC). In 1995, the group joined the Canadian Geophysical Union, as a committee of the Hydrology Section.

One of the main committee activities is the sponsorship of workshops and short courses and the publication of proceedings. It also has a lot of research papers, practical investigation,s and case studies available on its website.

Canadian Geophysical Union
CRIPE Chair: Brian Morse, PhD
Professeur agrégé
Département de génie civil local 3947
Pavillon Adrien-Pouliot Université Laval
Cité Universitaire
Sainte Foy (Québec) G1K 7P4
Tel: (418) 656-2867
Fax/télécopieur: (418) 656-2928
E-mail: brian.morse@gci.ulaval.ca

CRIPE Secretary:
Dan Healy, PhD, PEng
Water Resources Engineer
AMEC Earth & Environmental
4810 - 93 Street
Edmonton, AB T6E 5M4
Tel: (780) 944-6367 Fax: (780) 944-6375
E-mail: dan.healy@amec.com
http://www.cripe.ca
[Last accessed: March 24, 2011]

FOREIGN/INTERNATIONAL

Note: The circumstances concerning flooding, flood-plain management, and flood damage reduction, and the legal and governance frameworks that apply in foreign countries differ from those in Canada. Inclusion of these agencies in no way implies that similar or greater expertise does not exist in Canada.

The Association of State Floodplain Managers

2809 Fish Hatchery Road, Suite 204
Madison, WI 53713
Tel: (608) 274-0123 Fax: (608) 274-0696
E-mail: memberhelp@floods.org
http://www.floods.org
[Last accessed: March 24, 2011]

The Association of State Floodplain Managers is an organization of professionals involved in floodplain management, flood hazard mitigation, the National Flood Insurance Program, and flood preparedness, warning, and recovery in the United States. ASFPM has become a respected voice in floodplain management practice and policy in the United States.

Chartered Institution of Water and Environmental Management (CIWEM)

15 John Street, London WC1N 2EB
United Kingdom
Tel: 020 7831 3110 Fax: 020 7405 4967
Director of Policy and Technical:
Justin Taberham
E-mail: justin@ciwem.org
http://www.ciwem.org
Webpage on flooding: **http://www.ciwem.org/policy-and-international/current-topics/flooding.aspx**
[Last accessed: February 23, 2011]

CIWEM is an independent, chartered professional body and registered charity with an integrated approach to environmental, social, and cultural issues. Using its volunteer base, it can advise governments and the wider community about the development of environmental policy with the goal of sustainable development. The Journal of Flood Risk Management is published in partnership with CIWEM and with the support of MWH by Wiley and is available by subscription from cs-journals@wiley.com

Environment Agency (UK)

Horizon House, Deanery Road,
Bristol BS1 5AH
Head Office Telephone: 08708 506506
General Inquiries telephone from outside the UK:
00 44 1709 389 201 (Mon–Fri, 8am–6pm)
Acting Director: David Rooke
Coastal and Flood Plain Management
http://www.environment-agency.gov.uk
http://www.environment-agency.gov.uk/research/planning/118129.aspx
[Last accessed: February 23, 2011

The Environment Agency is the principal flood risk management operating authority in the United Kingdom. It has the power (but not the legal obligation) to manage flood risk from designated main rivers and the sea. In relation to other rivers in England and Wales, these functions are undertaken by Local Authorities or Internal Drainage Boards. The Environment Agency is also responsible for increasing public awareness of flood risk and flood forecasting and warning, and it has a general supervisory duty for flood risk management.

Intergovernmental Panel on Climate Change (IPCC)

IPCC Secretariat
c,o World Meteorological Organization
7bis Avenue de la Paix, C.P. 2300
CH-1211 Geneva 2, Switzerland
Phone: +41-22-730-8208/54/84
Fax: +41-22-730-8025/13
Program Officer: Dr. Mary Jean Burer
Tel: (4122) 730 8521
E-mail: mburer@wmo.int
http://www.ipcc.ch
[Last accessed: March 24, 2011]

IPCC was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. It is the leading international body for the assessment of climate change.

IPCC is an intergovernmental body open to all member countries of the United Nations (UN) and the WMO. Currently, 194 countries are IPCC members.

IPCC is a scientific body that reviews the information relevant to climate change. It does not conduct its own research or data collection. Thousands of scientists from all over the world contribute to the work of the IPCC on a voluntary basis.

IPCC provides Assessment Reports of the state of knowledge on climate change. The latest one is Climate Change 2007, the IPCC Fourth Assessment Report. The next assessment report (AR5) is underway.

The Hydrologic Engineering Center (HEC)

U.S. Dept. of The Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616-4687
HEC Tel: (530) 756-1104 HEC Fax: (530) 756-8250
http://www.hec.usace.army.mil
[Last accessed: March 24, 2011]

The Hydrologic Engineering Center (HEC), an organization within the US Army Corps of Engineers' Institute for Water Resources. It is a centre of expertise respecting surface and groundwater hydrology, river hydraulics and sediment transport, and hydrologic statistics and risk analysis. Several hydrologic and hydrodynamic models are available for download from the HEC website.

USACE Cold Regions Research and Engineering Laboratory (CRREL)

72 Lyme Road
Hanover, New Hampshire 03755-1290
Tel: (603) 646-4100
E-mail: info@crrel.usace.army.mil
Hydrology and Hydraulics
POC: Timothy Pangburn
Tel: (603) 646-4296
E-mail: Timothy.Pangburn@usace.army.mil
http://www.crrel.usace.army.mil
[Last accessed: March 23, 2011]

The US Army Cold Regions Research and Engineering Laboratory does research and provides expertise with respect to ice-jam mitigation measures and emergency operations, snowmelt, soil infiltration, and runoff, and hazard mitigation. CRREL also offers scientific research facilities for use by private industry and academia. Its website contains many downloadable technical publications.

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———. 2001b. *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of IPCC Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

———. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

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UNISDR (United Nations International Strategy for Disaster Reduction). 2002. *Guidelines for Reducing Flood Losses*. Geneva, Switzerland: UN. [Online.] **http://www.unisdr.org/we/inform/publications/558 (accessed February 4, 2012).**